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13. ABSTRACT *(Maximum 200 words)*

Experimental investigations have been carried out on forward mode optical phase conjugation in $Hg_{1-x}Cd_xTe$ using CO_2 Q-switched and TEA lasers. The temperature dependence of the degenerate four-wave mixing signal at 10.6 um has been studied for four n-type samples (x=0,211, 0.216, 0.229, 0.233) and one p-type (x=0,236) between $80^{\circ}K$ and $300^{\circ}K$. Formation and erasure of a dynamic electron grating in an n-type x=0,216 sample has been studied. One oral publication has been submitted for later presentation.

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1.0 RESEARCH OBJECTIVES

The objectives of the contract are listed below:

(1) Determine the dependence of the power reflection coefficient upon signal and pump intensities for optical phase conjugation by resonant four-wave mixing in mercury cadmium telluride crystals.

(2) Study optical phase conjugation by four-wave mixing in epitaxial layers of mercury cadmium telluride.

(3) Investigate noncollinear phase matched far infrared radiation in mercury cadmium telluride.

(4) Measure the spectral dependence of the optical absorption coefficient in mercury cadmium telluride from 10 to 50 micrometers and separate band edge absorption with possible exciton effects from intervalence band and free carrier absorption.

(5) Measure the spectral dependence of the quantum efficiency in small gap mercury cadmium telluride from 10 to 50 micrometers.

(6) Determine the relative contributions of the microscopic mechanisms, including conduction band nonparabolicity, photoexcited plasma, and saturable absorption, to optical phase conjugation in $Hg_{1-x}Cd_xTe$.

(7) Investigate the quality of the phase conjugate return in $Hg_{1-x}Cd_xTe$.

(8) Investigate optical bistability in $Hg_{1-x}Cd_xTe$ arising from third order nonlinearities.

(9) Investigate theoretically the response time of nonlinear optical interactions produced by the various microscopic mechanisms in semiconductors.

(10) Investigate theoretically the nonlinear optical interaction mechanisms in semiconductor superlattices.

2.0 STATUS OF RESEARCH EFFORT AND FUTURE PLANS

2.1 Nonlinear Optics Experimental Investigations - Status

In the period 9 January - 8 July 1984 experiments were carried out to study the dynamics of real time electron gratings formed in $Hg_{1-x}Cd_xTe$ by the interference of two CO_2 laser beams. The objectives of these experiments were to

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- Demonstrate light diffraction from real-time electron gratings formed in $Hg_{1-x}Cd_xTe$.

- Study the dynamics of these gratings by measuring their formation/erasure times.

- Understand the microscopic mechanism responsible for the grating formation.

The experimental arrangement is illustrated in Figure 1. Two parallel polarized laser beams were obtained by beam splitting either a Q-switched CO_2 laser or a TEA-CO_2 laser. Both lasers emit 10.6 μm radiation. The peak power density incident upon the sample from the Q-switched laser pump was 100 W/cm^2; that from the TEA laser was 1 MW/cm^2. The pump and probe beams which have an included angle of 5° were incident on $Hg_{1-x}Cd_xTe$ samples mounted inside a Joule-Thomson cryostat within which the temperature could be precisely controlled between 300°K and 80°K. This ability to vary the temperature in a continuous manner so as to provide information on the temperature dependence of the four-wave mixing signal is an important new feature of the experiments. Interference between the pump and probe beams resulted in an electronic grating inside the crystal. Each beam was subsequently diffracted by this grating to form a forward mode phase conjugate signal. The signal resulting from the diffraction of the pump beam, which was of greater interest, was monitored using a Ge:Cu detector and displayed on a programmable storage oscilloscope.

In order to interpret the data which follow, it is necessary to review some observations regarding the microscopic mechanisms which have been determined in previous investigations under the contract. They are as follows:

- Under low levels of excitation by a 10.6 μm CO_2 laser, such as 100 W/cm^2 from a Q-switched laser, the operable mechanism is the photoexcited plasma. The magnitude of the effect is strongly dependent upon resonance between the band edge and the laser wavelength. It occurs in either n- or p-type material, and has a relatively long response time, in the nsec to μsec range, arising from recombination of the photoexcited carriers.

- Under high levels of excitation by a 10.6 μm CO_2 laser, such as 1 MW/cm^2 from a TEA laser, the operable mechanism is conduction band nonparabolicity. This is found only in n-type material, and also shows resonant enhancement when the band edge coincides with the laser wavelength. The response time, the electron relaxation time is extremely short, in the psec range. Note that under this high excitation intensity, the photoexcited plasma mechanism has saturated.

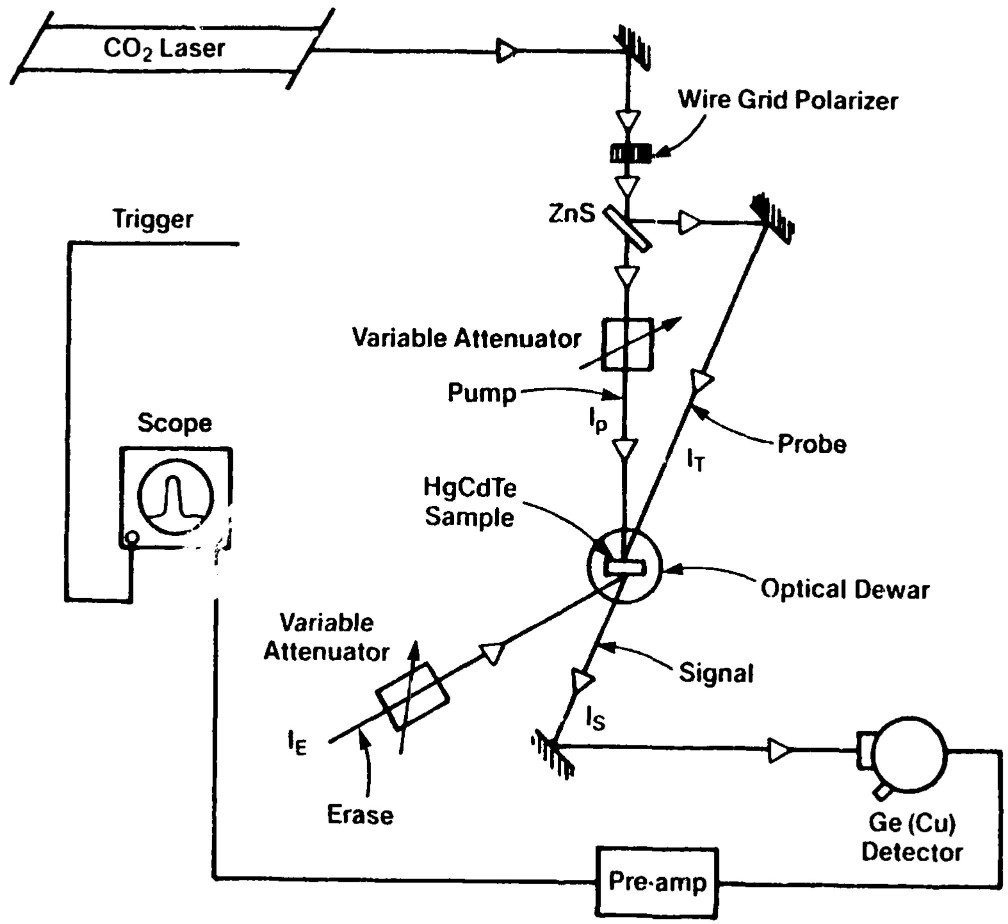


FIGURE 1

Experimental Arrangement

- Although not as well established in $Hg_{1-x}Cd_xTe$ as the above mechanisms, under high levels of excitation such as provided by a CO_2 TEA laser, a two-photon absorption mechanism may be operable. For samples in which the absorption edge is shorter than 10.6 μm, this mechanism may lead to the production of hole-electron pairs. The resulting absorption will be nonlinear.

Of the five samples employed in the studies reported herein, only the x=0.211 and 0.216 samples had band edges at 10.6 μm at temperatures greater than 0°K. That for x=0.211 is 80°K; for 0.216 is 70°K. The other three samples (x=0.229, 0.233, and 0.236) had band edges shorter than 10.6 μm at all temperatures above 0°K.

The previous semiannual report made reference to a plan to measure the grating formation and erasure times to an accuracy of 1 μsec or better. For this purpose the first set of experiments that were carried out during the present period employed an n-type sample having an x-value of 0.216. A 10.6 μm Q-switched CO_2 laser was employed for the pump and probe beams. The signal resulting from the nonlinearity due to plasma excitation was detected by the Ge:Cu detector and displayed on the oscilloscope. The timing of these signals on the scope indicated that the formation of the electronic gratings is clearly faster than 1 μsec. The signal in this case was monitored as a function of crystal temperature. As expected, a sharp resonance in the signal due to the fundamental absorption edge tuning with temperature so as to coincide with the 10.6 μm laser radiation is seen, see Figure 2. However, the predicted temperature is 70°K, rather than the observed 110°K.

This experiment was repeated using an x=0.236 p-type sample. A strong signal was again observed (S/N $\sim$ 100) which increased with decreasing temperature. Although the absorption edge never is resonant with the CO_2 laser at any temperature, it is almost resonant (10.0 μm) near 0°K.

These two experiments indicate that when a Q-switch laser is employed as the pump the diffracted signals arise from plasma nonlinearities. As expected, the signal in this case is independent of the electrons in the conduction band, and can be found in both n- and p-type crystals. The magnitude depends upon the match between the bandgap energy and the pump laser energy. Since the signal from the x=0.236 p-type sample persists even at room temperature, see Figure 2, it is possible that there exists in that sample a nonlinear mechanism in addition to plasma excitation. It cannot be conduction band nonparabolicity since that is not an operable mechanism in p-type material.

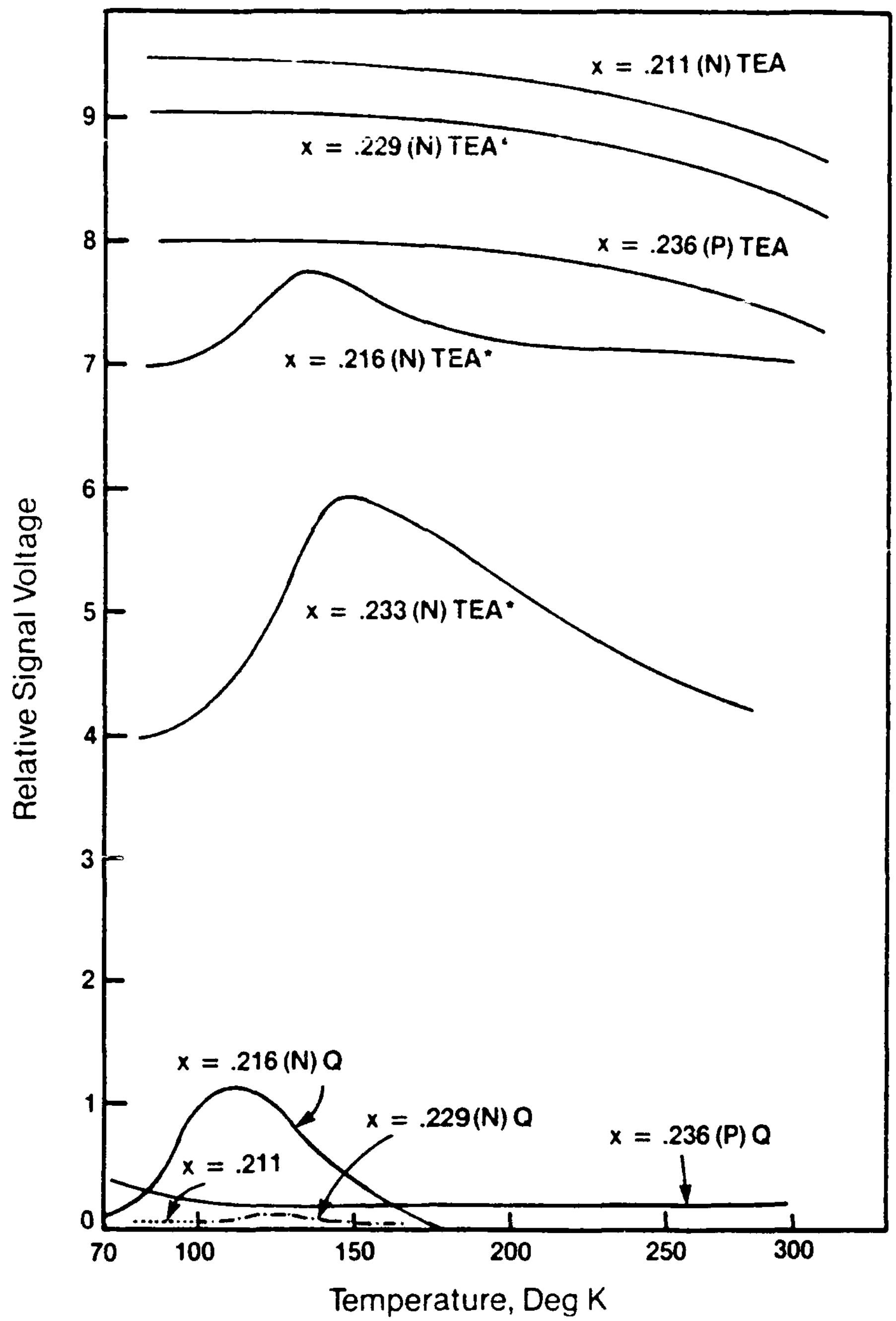


FIGURE 2

Signal vs Temperature
for $Hg_{1-x}Cd_xTe$ Crystals
Using CO_2 TEA Laser (1 MW/cm^2) and
Q-Switched Laser (100 W/cm^2)

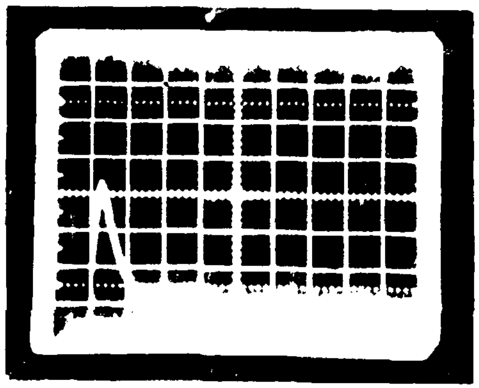
In the next series of experiments the CO_2 Q-switched laser was replaced by a CO_2 TEA laser. This was done to study real-time electron gratings and the third order nonlinearity arising from conduction band nonparabolicity. In this series of experiments an erase beam was also incident on the x=0.216 crystal from the back side. It was found possible to erase completely the electron grating by this means, see Figure 3. The formation and erasure of gratings using the TEA laser beams was found to be faster than 1-2 ns, which is the rise and fall time of the TEA laser pulses.

The grating erasure was determined to be independent of the sample temperature, depending only on the erase beam power. A tentative explanation involves two-photon absorption of the erase beam to create electron-hole pairs. This decreases the diffracted signal due to a strong absorption at 10.6 μm by the holes, due to an increase in the effective band gap energy (dynamic Burstein-Moss effect), or due to the bleaching of the carriers in the valence band which are needed for the plasma effect. More work is in progress to understand the microscopic mechanism responsible for this write/erase process. It is important to realize that this technique provides a method of modulating electron gratings with a speed faster than 1 ns. The diffraction efficiency was found to be about 15%. To the best of our knowledge this is the first demonstration of modulation speeds of 1 ns using semiconductor solids.

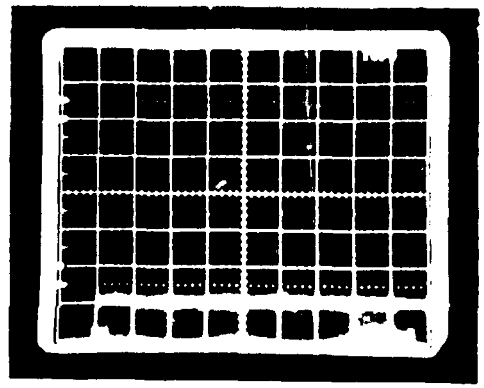
Figure 2 also shows the signals from three other n-type samples having x-values of 0.211, 0.229, and 0.233 as a function of temperature. These signals were obtained using a TEA laser pump and hence are attributed to the conduction band nonparabolicity mechanism. The resonant behavior exhibited by the x=0.233 sample is not understood, since at 0°K the absorption edge lies at about 9.8 μm, and decreases with increasing temperature. The x=0.236 p-type sample also gave rise to a strong signal when pumped with a TEA laser at 10.6 μm. This cannot be due to conduction band nonparabolicity because there are no conduction electrons in p-type material. It is not due to the plasma nonlinearity because those signals saturate at about 100 W/cm^2 pump intensity. Thus, there is some other nonlinear mechanism that takes place in p-type $Hg_{1-x}Cd_xTe$ which has not been reported to date. This will be studied in more detail in the future.

2.2 Nonlinear Optics Experimental Investigations - Plans

In the second half of 1984, the microscopic mechanisms giving rise to the real-time electron gratings and the subsequent light diffraction by them will continue to be investigated. $Hg_{1-x}Cd_xTe$ crystals with x-values ranging from 0.20 to 0.23 will be employed. Using these crystals and a line-tunable CO_2 TEA laser, the diffracted signals will be studied as a function of x-values, pump laser



Signal with erase beam blocked



Signal with erase beam on

FIGURE 3

Oscilloscope Photos Illustrating Signal Erasure
(10 μSec/Division)

wavelength and sample temperature. The diffracted signal data, corrected for absorption in the crystals, will be used to further elucidate the nature of the microscopic mechanisms responsible for the diffraction process.

2.3 Nonlinear Optics Theoretical Investigations - Status

Because a replacement has not yet been found for Dr. Darryl Smith, no theoretical investigations were carried out during this reporting period.

2.4 Nonlinear Optics Theoretical Investigations - Plans

The search for a replacement for Dr. Smith will continue.

3.0 WRITTEN PUBLICATIONS IN TECHNICAL JOURNALS

No papers were submitted or published during this period.

4.0 PROFESSIONAL PERSONNEL ASSOCIATED WITH RESEARCH EFFORT

The following personnel with B.S. or higher degrees participated in the research effort during the period 9 January 1984 - 8 July 1984.

Dr. Paul W. Kruse, Chief Research Fellow
Dr. Muhammad A. Khan, Senior Principal Research Scientist
Mr. John A. Lehman, Student Aide

5.0 INTERACTIONS

5.1 Spoken Papers Presented at Meetings

No papers were presented during the period 9 January 1984 - 8 July 1984. One paper has been submitted for presentation at the International Conference on Lasers '84, to be held in San Francisco on 26-30 November 1984:

- M. Asif Khan, J. Lehman, and P.W. Kruse, "Dynamics of Real-Time Electron Gratings in $Hg_{1-x}Cd_xTe$".

5.2 Consultative and Advisory Functions

None

5.3 Other Interactions

None

6.0 NEW DISCOVERIES, INVENTIONS, OR PATENT DISCLOSURES

The erasable electron grating will be submitted to Honeywell's patent department as an invention disclosure.